INTERFERENCE FRAGMENTATION FUNCTIONS AND SPIN ASYMMETRIES

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A new class of fragmentation functions, arising from the interference of different hadron production channels, is analyzed in detail. Their symmetry properties with respect to naive time-reversal transformations allow for the exploration of final-state interactions occurring during and after the hadronization. Their symmetry properties with respect to chiral transformations allow building spin asymmetries where the quark transversity distribution can be factorized out at leading twist. Explicit calculations will be shown for the interference fragmentation functions arising from final-state interactions of two pions detected in the same current jet for the case of semi-inclusive Deep-Inelastic Scattering (DIS).

Because a rigorous explanation of confinement is still far from being achieved, information on the nonperturbative nature of quarks and gluons inside hadrons can be extracted from distribution (DF) and fragmentation (FF) functions in hard scattering processes. There are three independent DF that completely determine the quark status inside hadrons at leading twist with respect to its longitudinal momentum and spin: the momentum distribution f_1, the helicity distribution g_1 and the transversity distribution h_1. In contrast to the first two ones, h_1 is related to soft processes that flip chirality; as such, h_1 is, e.g., unaccessible in inclusive DIS. However, the new generation of machines (HERMES, COMPASS, eRHIC) allows for a better resolution in the final state and precise semi-inclusive measurements are becoming feasible. In this context, naive time-reversal odd (for brevity, "T-odd") FF naturally arise because no constraints from time-reversal invariance can be imposed due to the existence of Final State Interactions (FSI) with or inside the residual jet [1]. The interference of different hadron production channels produces a new set of T-odd FF which are also chiral odd, and, therefore, they represent the natural partner to isolate h_1 already at leading twist, whereas other tools like Drell-Yan processes seem less favoured [2].

From the theoretical point of view, it is convenient to select DIS processes where two unpolarized leading hadrons with momenta P_1 and P_2 are detected in the same jet, that acts as a spectator [3,4], and generalize the Collins-Soper light-cone formalism [5] to this case. At leading twist, four FF appear: $D_1, G_1^{\perp}, H_1^{\perp}, H_1^{\sphericalangle}$ [4]. In the frame where the transverse component of the 3-momentum transfer vanishes, $\mathbf{q}_\perp = 0$, they depend on how

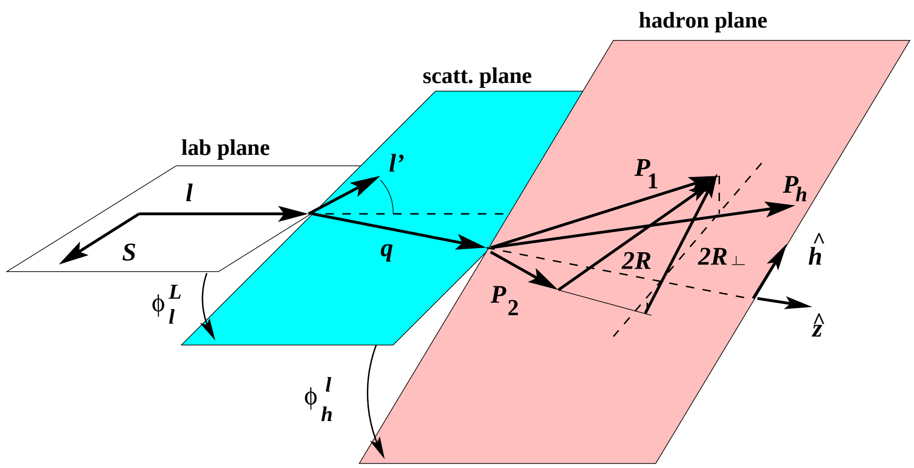

Figure 1. Kinematics for semi-inclusive DIS where two leading hadrons are detected (see text).

much of the fragmentig quark momentum k is carried by the hadron pair ($z = (P_1 + P_2)^-/k^- \equiv P_h^-/k^- = z_1 + z_2$), on the way this momentum is shared inside the pair ($\xi = z_1/z$), and on the "geometry" of the pair, namely on its transverse relative momentum ($\mathbf{R}_\perp^2$, with $R = (P_1 - P_2)/2$), on the relative position of the pair total momentum P_h with respect to the jet axis $\hat{\mathbf{k}} = \mathbf{k}/|\mathbf{k}|$ (i.e. $\mathbf{k}_\perp^2$), and on the relative position between the pair plane, formed by P_1 and P_2, and the plane containing P_h and the jet axis (i.e. $\mathbf{k}_\perp \cdot \mathbf{R}_\perp$). Each FF is also related to a specific spin state of the fragmenting quark: $H_1^\perp$ is the analogue of the Collins function for the one hadron semi-inclusive DIS [6]; on the contrary, $H_1^{\triangleleft}$ represents a genuine new effect relating the transverse polarization of the fragmenting quark to the transverse relative dynamics of the detected pair, namely $\mathbf{R}_\perp$. $G_1^\perp, H_1^\perp, H_1^{\triangleleft}$ are "T-odd" and are nonvanishing only in the presence of residual FSI, at least between the two hadrons. $G_1^\perp$ is chiral even, while both $H_1^\perp, H_1^{\triangleleft}$ are chiral odd and can be identified as the chiral partner needed to access the transversity h_1 [4].

The cross section at leading twist for the process $eN \to e'h_1h_2X$ has been worked out in detail in Ref. [4]. Here, we will reconsider the case for an unpolarized beam and a transversely polarized target. The lab frame can be defined by the plane containing the beam 3-momentum $\mathbf{l}$ and the target polarization $\mathbf{S}$ (see Fig. 1). The scattering plane, which contains the scattered lepton 3-momentum $\mathbf{l}'$ and $\mathbf{l}$, is rotated by the azimuthal angle ϕ_l^L. Finally,

the socalled hadronic plane, which contains $\mathbf{q} = \mathbf{l} - \mathbf{l}'$ (conventionally parallel to the $\hat{\mathbf{z}}$ axis) and $\mathbf{P}_h$, is rotated by $\phi_h^L = \phi_h^l + \phi_l^L$. A further plane, which is just sketched in Fig. 1 for sake of simplicity, contains $\mathbf{P}_1, \mathbf{P}_2, \mathbf{R}$ and its transverse component $\mathbf{R}_\perp$; it is rotated by $\phi_R^L = \phi_R^l + \phi_l^L$ with respect to the lab. The nine-fold differential cross section depends on the energy fraction taken by the scattered lepton ($y = q^0/|\mathbf{l}|$), on ϕ_l^L, on the quark light-cone momentum fraction $x = p^+/P^+$ of the target momentum P, on $z, \xi, \mathbf{R}_\perp$ and $\mathbf{P}_{h\perp}$. Since $R_\perp^2 = \xi(\xi-1)P_h^2 - (1-\xi)P_1^2 - \xi P_2^2$ [4], the cross section can be more conveniently considered differential with respect to the pair invariant mass $P_h^2 = M_h^2$ and ϕ_R^L. By integrating over the "internal" dynamics (i.e. on $\xi, \mathbf{k}_\perp, \mathbf{P}_{h\perp}$) and by properly folding the cross section over the experimental set of beam and hadron-pair azimuthal positions ϕ_l^L and ϕ_R^L, it is possible to come to the factorized expression

$$
\begin{aligned}
\langle d\sigma_{OT} \rangle &\equiv \int d\phi_l^L \, d\phi_R^L d\mathbf{P}_{h\perp} \, d\xi \, \sin(\phi_R^L - 2\phi_l^L) \frac{d\sigma_{OT}}{dy \, d\phi_l^L \, dx \, dz \, d\xi \, dM_h^2 \, d\phi_R^L \, d\mathbf{P}_{h\perp}} \\
&= \frac{\alpha_{em}^2 s}{4\pi^2 Q^4} \, \frac{(1-y)|\vec{S}_\perp|}{M_1 + M_2} \sum_a e_a^2 x \, h_1^a(x) \, H_1^{\sphericalangle\, a}(z, M_h^2) \qquad (1)
\end{aligned}
$$

where α_{em} is the electromagnetic fine structure constant, $s = Q^2/xy$ is the total energy in the center-of-mass frame, M_1, M_2 are the masses of the two observed hadrons, and a sum over the flavor a of each quark with charge e_a is performed (see also Ref. [7]). It is worth noting that such a factorized form can be reached requiring one less variable than in the case of one hadron emission with the Collins functions, where also knowledge of $|\mathbf{P}_{h\perp}|$ is needed [2].

Quantitative predictions for the integrated $H_1^{\sphericalangle\, a}$ in Eq. (1) can be produced by specializing the spectator model of Ref. [8] to the case of the emission of a hadron pair. For the hadron pair being a proton and a pion, results have been published in Ref. [9], where FSI arise from the interference between the direct production and the Roper decay. Here, results are shown for the case of two pions with invariant mass in the range $[m_\rho - \Gamma_\rho, m_\rho + \Gamma_\rho]$, with $m_\rho = 768$ MeV and $\Gamma_\rho \sim 250$ MeV. The spectator state has the quantum numbers of an on-shell quark with constituent mass $m_q = 340$ MeV. Interference "T-odd" FF arise from the interference between the direct production and the ρ decay. In Fig. 2, $\alpha_{em}^2/[8\pi^2 m_\pi] \times H_1^{\sphericalangle}(z, M_h^2 = m_\rho^2)$ of Eq. (1) is shown for the case $u \to \pi^+\pi^-$. It shows that a nonvanishing integrated interference FF survives allowing for the extraction of h_1 at leading twist, as suggested in Eq. (1).

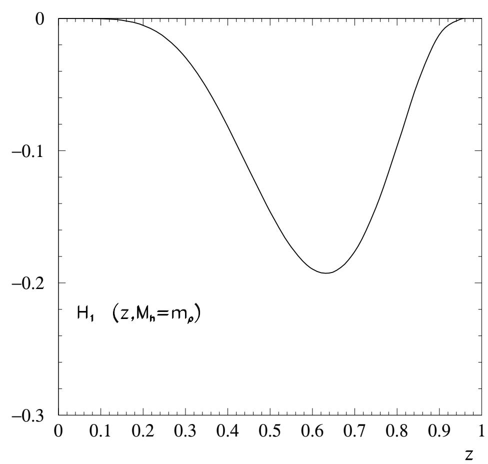

Figure 2. The fragmentation function $\alpha_{em}^2/[8\pi^2 m_\pi] \times H_1^{\triangleleft}(z, M_h^2 = m_\rho^2)$ of Eq. (1) for the $u \to \pi^+\pi^-$ case.

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